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SPECTRAL EMISSIVITY OF CIRRUS CLOUDS

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1. Introduction

The inference of cirrus cloud properties has many important applications including global climate studies, radiation budget determination, remote sensing techniques and oceanic studies from satellites.

Data taken at the Parsons, Kansas site during the FIRE II project are used for this study. On November 26 there were initially clear sky conditions gradually giving way to a progressively thickening cirrus shield over a period of a few hours. Interferometer, radiosonde and lidar data were taken throughout this event.

Two techniques are used to infer the downward spectral emittance of the observed cirrus layer. One uses only measurements and the other involves measurements and FASCODE III calculations. FASCODE III is a line-by-line radiance/transmittance model developed at the Air Force Geophysics Laboratory.

2. Instrumentation

The infrared interferometer employed in this study is a dual port emission Michelson interferometer manufactured by Bomem, Inc. It has an adjustable resolution ranging from 1 cm-1 to 128 cm-1; the FIRE II data were taken with the interferometer at the 1 cm-1 setting. The detector is liquid nitrogen cooled and has a useful range from 500 cm-1 to 2000 cm-1.

The spectral range used for this investigation extends from 740 cm-1 to 1260 cm-1. This range includes all of the atmospheric window and reaches beyond it's edges (see fig.1). The edge of the CO_2 absorption band is apparent on the low wavenumber end and the edge of the H_2O absorption region is apparent on the other.

3. Methodology

Two techniques are developed for inferring the infrared emittance of cirrus layers from surface-based interferometer measurements. The first technique is the observational method. This method requires interferometric clear sky and cirrus sky spectra, lidar returns and radiosonde data. The second technique is the semi-empirical method. The semi-empirical method uses FASCODE III calculations, clear sky interferometer spectra, lidar returns and radiosonde data.

The effects of scattering were ignored for the FASCODE calculations. The scattering of IR radiation by air molecules is negligible although the scattering caused by aerosols falls into the Rayleigh regime and for cloud droplets or ice crystals it enters the Mie regime, however, the absorption and emission by these larger particles is far more significant than any effect of scattering.

The effects of reflection are ignored for the calculations of the emittance and transmittance of the cirrus.

3.1 Observational technique

In the observational technique interferometric data obtained just before the onset of the cirrus are used with the data obtained following the advancement of the cirrus shield overhead. The data used for this analysis were taken at 1610Z and 2005Z respectively Nov. 26 (see fig.1). The effective radiance from the cirrus cloud is found by spectral differencing, i.e. the cirrus sky radiance minus the clear sky radiance. Using a simple 3 layer model (see fig.2), the equations for the cirrus sky radiance and the clear sky radiance are as follows:

$$(1) \quad N_{mcld} = N_l + N_{cld}\, T_l + N_u\, T_{cld}\, T_l$$
$$(2) \quad N_{mclr} = N_l + N_{clr}\, T_l + N_u\, T_{clr}\, T_l$$

where N_{mcld}: measured radiance at the surface with cirrus present
N_{mclr}: measured radiance at the surface with clear sky
N_l : radiance from the atmosphere below the cirrus layer
N_{cld} : radiance from the cirrus layer with the cloud present
N_{clr} : radiance from the cirrus layer if it were clear
T_l : transmittance of the atmosphere below the cirrus layer
N_u : radiance from the atmosphere above the cirrus layer
T_{cld} : transmittance of the cirrus layer with the cloud present
T_{clr} : transmittance of the cirrus layer if it were clear

The layer radiances are as would be seen at the respective lower boundary of the layer looking upward with no effects from outside that layer.

For spectral differencing, equation (2) is subtracted from equation (1) to obtain the effective downward radiance from the cirrus cloud:

$$(3) \quad N_{eff} = N_{mcld} - N_{mclr} = [(N_{cld} - N_{clr}) - N_u\, (T_{clr} - T_{cld})]\, T_l$$

In equation (3), the effective downward radiance N_{eff} (see fig.3) is the composite of two terms multiplied by the transmittance (T_l) of the sub-cloud layer. $N_{cld} - N_{clr}$ represents the increase in radiance from the cirrus layer with the cloud present. The $N_u\, (T_{clr} - T_{cld})$ term represents the decrease in the radiance (N_u) from above the cirrus layer due to the decrease in transmittance of the cirrus layer when the cloud is present, as seen from the base of the cloud layer. An effective emittance (see fig.4) may be found via equation (4), again ignoring reflection:

$$(4) \quad E_{eff} = N_{eff} / B_{cld}$$

B_{cld} is the Planck function of the cirrus layer temperature. The cloud base temperature determined from lidar and sounding data was used for this study.

3.2 Semi-empirical technique

Interferometric cirrus sky spectra taken at 2005Z were used in this application. The sounding data used to initialize FASCODE was from a sonde launched at 1936Z. The sonde travelled through the cirrus layer from 2000Z to 2015Z according to lidar data which showed the cirrus layer extending from 6.5 km to 10 km. Restating equation (1) from the previous page:

$$(5) \quad N_{mcld} = N_l + N_{cld}\, T_l + N_u\, T_{cld}\, T_l$$

In equation (5), N_l, T_l and N_u can be calculated using FASCODE with the available sounding data. This leaves two unknowns, N_{cld} and T_{cld}. Since we are ignoring the effects of reflection:

$$(6) \quad E_{cld} = 1 - T_{cld}$$

E_{cld} is the emissivity of the cirrus layer. Since the radiance from the cloud layer is given by (E_{cld} * B_{cld}), using equation (6):

$$(7) \quad N_{cld} = B_{cld}\,(1 - T_{cld})$$

Substituting equation (7) into equation (5):

$$(8) \quad N_{mcld} = N_l + B_{cld}\,(1 - T_{cld})\, T_l + N_u\, T_{cld}\, T_l,$$

And solving for the cirrus layer transmittance T_{cld}:

$$(9) \quad T_{cld} = (N_{mcld} - N_l - B_{cld}\, T_l) / [(N_u - B_{cld})\, T_l]$$

After solving for the transmittance, the radiance of the cirrus layer may then be found using equation (7). This is the downward radiance from the cirrus as would be observed at the lower boundary of the layer (see fig.5) excluding any effects from above the layer. The emittance (see fig.6) of the cirrus layer may then be found using equation (6).

3.3 Comparison of the two techniques

A direct comparison of these two methods can be made by normalizing the cirrus layer properties found with the semi-empirical method. Since the information found in the semi-empirical method is for the cirrus layer exclusively, equation (3) may be applied to deduce a simulated finite difference radiance, i.e., to simulate the radiance as seen by the surfaced-based inteferometer. N_u and T_l were previously found with FASCODE in the semi-empirical method, then N_{cld} and T_{cld} were found. By using FASCODE to calculate the radiance (N_{clr}) and transmittance (T_{clr}) of the cirrus layer if it were clear, all the information needed to solve for the effective radiance is available. Finally, a direct comparison may be made by solving for the resulting effective emittance (see figs.7 and 8) via equation (4).

4. Conclusions

The radiance curves deduced from the two methods are very similiar. The observational method (see fig.3) yielded an integrated radiance of 6.31 W m-2 sr-1 and the semi-empirical method (see fig.7) 6.50 W m-2 sr-1. A comparison of the emittances also shows very similiar structure. The spectrally averaged emittance from 740 cm-1 to 1260 cm-1 for the observational method (see fig.4) is 0.3537 while the average emittance for the semi-empirical method (see fig.8) is 0.3542 although the semi-empirical method yielded higher values throughout most of the window. These higher values were offset by the near zero values caused by noise in the nearly opaque water vapor absorption lines in the high wavenumber end of the spectrum and resulted in the average emissivity values being nearly identical.

A main source for discrepancy between the two datum is that the interferometric data and the FASCODE output are not processed in precisely the same manner. The numerical equivalent of the apodization used for the FASCODE analysis is currently under study. Another source of uncertainty is that the interferometer atmospheric data are taken within a period of about 2 minutes, while the sounding data used for FASCODE simulations isn't exact since it takes over an hour to acquire data and also drifts away from the launch site as a function of time.

5. Acknowledgments

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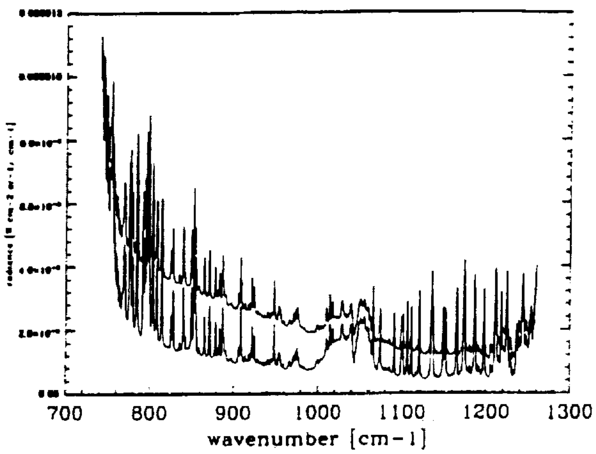

Fig.1. Comparison of the spectral radiance seen by the surfaced-based interferometer for clear sky (lower curve) and cirrus sky (upper curve) taken on Nov. 26 at Parsons.

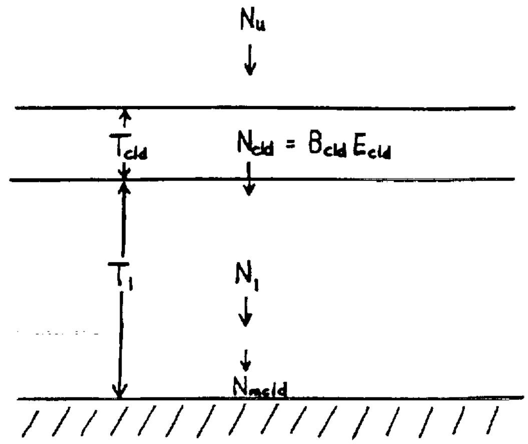

Fig.2. The three layer model used for this study.

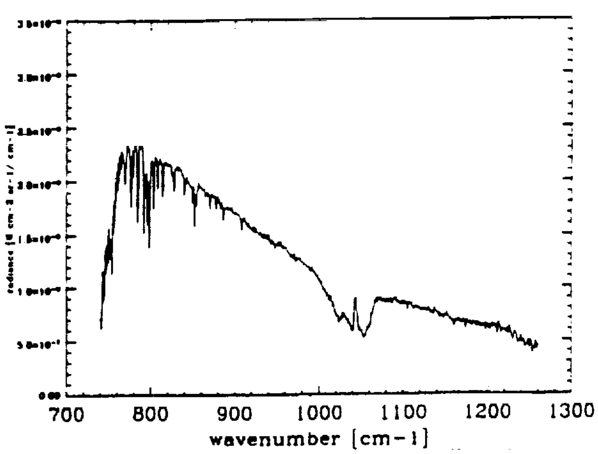

Fig.3. Effective spectral radiance found by spectral differencing the two curves in Fig.1.

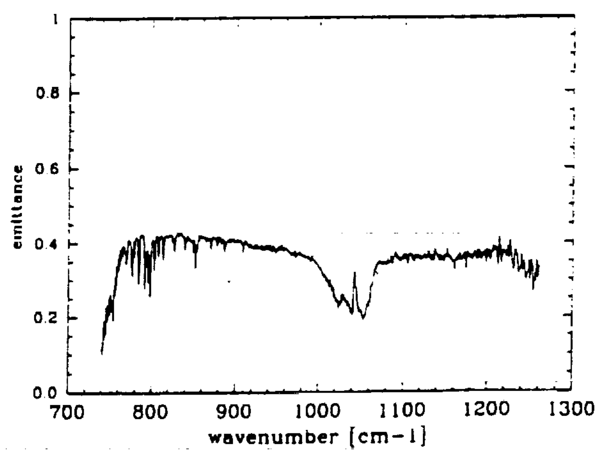

Fig.4. An effective spectral emmitance derived from the effective radiance shown in Fig.3.

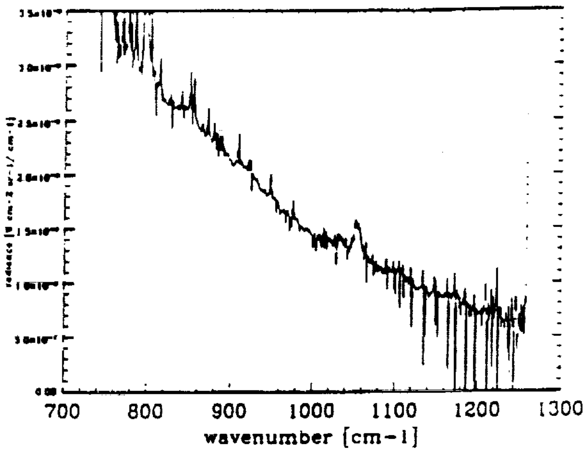

Fig.5. The downward spectral radiance of the cirrus layer as seen from the lower boundary of the cirrus layer.

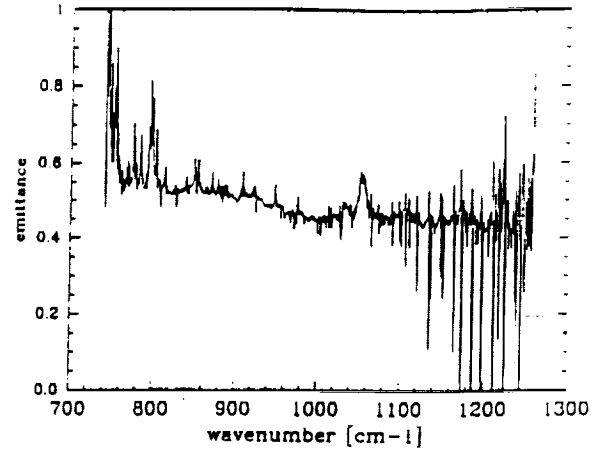

Fig.6. The spectral emittance of the cirrus layer.

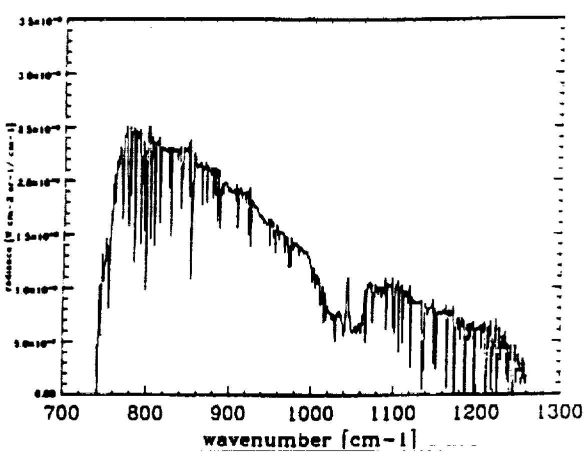

Fig.7. The simulated effective spectral radiance inferred from the interferometric cirrus radiance and FASCODE calculations.

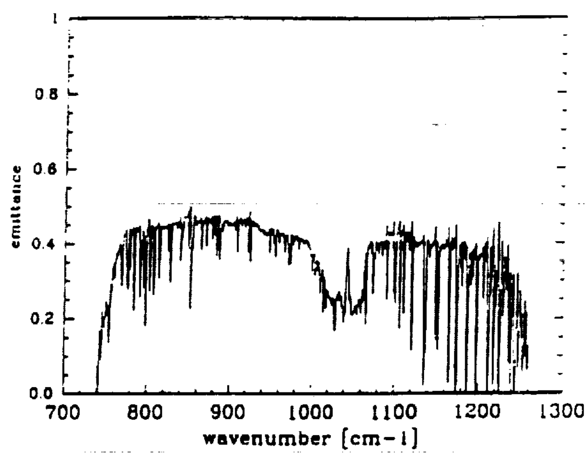

Fig.8. The simulated effective spectral emittance found using the information in Fig.7.